THE INVASIVE SHRUB *PIPER ADUNCUM* IN PAPUA NEW GUINEA: A REVIEW

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HARTEMINK AE. 2010. The invasive shrub *Piper aduncum* in Papua New Guinea: a review. *Piper aduncum* is a shrub native to Central America. It is found in most Central and South American countries and also in the Caribbean and southern Florida (USA). In Asia and the Pacific, *P. aduncum* occurs in Indonesia, Malaysia, Philippines, Papua New Guinea, Solomon Islands, Vanuatu, Fiji, Micronesia, American Samoa, Niue, the Marianas, Tonga, Samoa, the Cook Islands, Palau and Hawaii (USA). *Piper aduncum* arrived in Papua New Guinea before the mid-1930s. From the 1970s, it started to dominate the secondary fallow vegetation in many parts of the humid lowlands. It invaded grassland areas and also appeared in the highlands up to 2100 m asl. The seeds are dispersed by birds, bats and wind, as well as by logging equipment and in some localities, by migrating people. The combination of its vigorous generative characteristics (small and abundant seeds), high growth rate and the accidental or intentional spreading has resulted in its presence in most provinces of Papua New Guinea. In the 1990s, awareness of the spread of *P. aduncum* grew and there was a corresponding increase in research interest from a range of disciplines, e.g. pharmacology, agronomy, quarantine, forestry and taxonomy. The invasion of *P. aduncum* has affected the farming system and livelihood of many rural people. Future research should focus on mapping its extent, and studying its agronomic, socio-economic and ecological effects, particularly its effect on biodiversity.

Keywords: Bioinvasion, tropical forest, plant invaders, biodiversity, Pacific

HARTEMINK AE. 2010. Penguasaan pokok renek *Piper aduncum* di Papua New Guinea: tinjauan semula. *Piper aduncum* ialah sejenis pokok renek yang asli di Amerika Tengah. Pokok ini dijumpai di kebanyakan negeri Amerika Tengah dan Amerika Selatan termasuk di Caribbean dan selatan Florida (Amerika Syarikat). Di Asia dan Pasifik, *P. aduncum* dijumpai di Indonesia, Malaysia, Filipina, Papua New Guinea, Kepulauan Solomon, Vanuatu, Fiji, Micronesia, Samoa Amerika, Niue, Marianas, Tonga, Samoa, Kepulauan Cook, Palau dan Hawaii (Amerika Syarikat). *Piper aduncum* wujud di Papua New Guinea sebelum pertengahan tahun 1930-an. Mulai tahun 1970-an, *P. aduncum* menguasai vegetasi tanah rang sekunder banyak kawasan tanah pamah yang lembap. *Piper aduncum* membanjiri kawasan padang rumput dan juga dijumpai di kawasan tanah tinggi sehingga 2100 m dari aras laut. Biji benih *P. aduncum* disebar oleh burung, kelawar dan angin serta mesin pembalakan dan di beberapa tempat oleh orang yang berhijrah. Kehadiran *P. aduncum* di kebanyakan wilayah di Papua New Guinea disebabkan gabungan faktor iaitu ciri keturunan yang cergas (biji benih yang kecil dan banyak), kadar pertumbuhan yang cepat dan penyebaran biji benih secara tidak sengaja atau sengaja. Kesedaran tentang penyebaran *P. aduncum* mula berkembang pada tahun 1990-an dan ini berpadanan dengan bertambahnya minat dalam penyelidikan seperti farmakologi, agronomi, kuarantin, perhutanan dan taksonomi. Pembanjiran *P. aduncum* mempengaruhi sistem perladangan dan mata pencarian banyak penduduk luar bandar. Penyelidikan pada masa depan perlu fokus kepada pemetaan kawasan *P. aduncum* serta mengkaji kesan spesies ini terhadap agronomi, sosio-ekonomi dan ekologi, khasnya biodiversiti sesuatu kawasan.

INTRODUCTION

Plant invasion is recognised as an important component of the global biodiversity crisis that includes a loss of species and habitats. Some have argued that it is a threat more ominous than the greenhouse effect, industrial pollution or ozone depletion (Mack *et al.* 2001). Successful invasions tend to be concentrated in certain regions, especially islands and the temperate zone, suggesting that species-rich mainland and tropical locations are harder to invade because of greater biotic resistance—the so-called biotic resistance hypothesis (Blackburn & Duncan 2001). Mechanisms such as competition, resource partitioning, dispersal ability and predation tolerance explain some of the abundance of plant species under field conditions (Klironomos 2002).

Experiments have shown that natural plant abundance is related to the different rates at which soil pathogens develop on the roots of bioinvasive species. In new territories, plants are liberated from their native soil community, which results in two benefits: firstly, the invading plants escape from their soil pathogens but do not encounter new, species-specific ones. Secondly, mycorrhizal fungi can associate with a broad range of plant species, meaning that root symbionts are likely to be available to the invader (van der Putten 2002). Human activities greatly influence the spread and invasion of plants in new environments, particularly in tropical island environments.

Papua New Guinea is the largest tropical island. Due to its great range in climate and topography, it has a high diversity of both fauna and flora (Paijmans 1976). The forests of Papua New Guinea are as rich in species as those in Borneo or Malaysia, and richer than the African and South American forests. Due to logging activities and the expansion of additional cropland and agricultural plantations, forest areas have considerably declined over the past decades (McAlpine *et al.* 2001). The forest areas in the Morobe Province (34 000 km^2) decreased from 78 to 66% between 1975 and 2000 (Ningal *et al.* 2008). In addition to the loss of forest cover, there have been changes in the composition of secondary forest vegetation due to invasive plant species.

An overview of exotic plant species in Papua New Guinea has been provided by Orapa (2001) and Waterhouse (2003), following an earlier account by Henty and Pritchard (1988). Important invasive plants that are found in various parts of Papua New Guinea include *Rottboelia cochinchinensis*, *Sida acuta*, *Sida rhombifolia*, *Cyperus rotundus*, *Pennisetum purpureum*, *Imperata cylindrica*, *Mimosa invisa*, *Mimosa pudica*, *Mikania micrantha* and *Eichhornia crassipes*. Orapa (2001) considers the following invasive species as widespread weeds: *Chromolaena odorata*, *Mimosa pigra*, *Melinus minutiflora*, *Clerodendrum chinense*, *Parthenium hysterophorus*, *Stachytarpheta urticifolia*, *Sorghum halepense*, *Spathodea campanulata* and *Azadirachta indica*. *Piper aduncum* is also listed by Orapa (2001) as a newly introduced plant and has the potential to become an aggressive invader.

This paper reviews the current knowledge concerning *P. aduncum* in Papua New Guinea and has the following objectives, i.e. to (1) review the presence of *P. aduncum* in Asia and the Pacific, (2) trace its spread through Papua New Guinea based on botanical, ecological and ethnopharmacological literature, oral history, images and herbaria collections, and (3) discuss explanations for its success as well as its impact on farming systems and rural livelihoods.

Piper aduncum globally

Piper aduncum was first described scientifically in 1753 by Linnaeus. The plant was known before 1753 (the starting point for nomenclature) as Linnaeus cited three references, namely Plumier, van Royen and Sloane. The original material was collected in Jamaica (Hartemink 2006).

Piper aduncum is a shrub or small tree with alternate leaves and flowers and fruits arranged in a spike. It occasionally reaches a height of 7 to 8 m, and has very small fruits that are mostly dispersed by the wind, fruit bats and birds, but also by people and logging equipment. The commonest synonyms include *P. angustifolium, P. celtidifolium, P. elongatum, P. multinervium* and *P. stevensonii,* but there are several other synonyms for *P. aduncum.*

Piper aduncum occurs in South and Central America, North America, the West Indies, South-East Asia and the Pacific; it is probably not present in Africa. *Piper aduncum* is indigenous to tropical America where it is commonly found (Figure 1). It is especially common throughout Central America where it is found between sea level and 2000 m asl along roadsides and in forest clearings on well-drained soils. Its habitat is restricted to evergreen vegetation and near water courses in seasonally deciduous forests. It occurs in many countries on open or partly shaded sites (Burger 1971, Cicció & Ballestro 1997, Olander *et al.* 1998).

It has been described in Guatemala, Colombia, Venezuela, Brazil and southern Florida (Bornstein 1991) where it is on the unwanted weed species list. In Central and South America, *P. aduncum* may be locally abundant, but it rarely dominates the vegetation (R Callejas, personal communication) and is not found in mature vegetation. In the Amazon region of Brazil, it has been reported as an invading plant after deforestation (Maia *et al.* 1998).

It is often represented in tropical indoor greenhouses in North American gardens (A Bornstein, personal communication). In the USA, its leaves and fruits are sold commercially

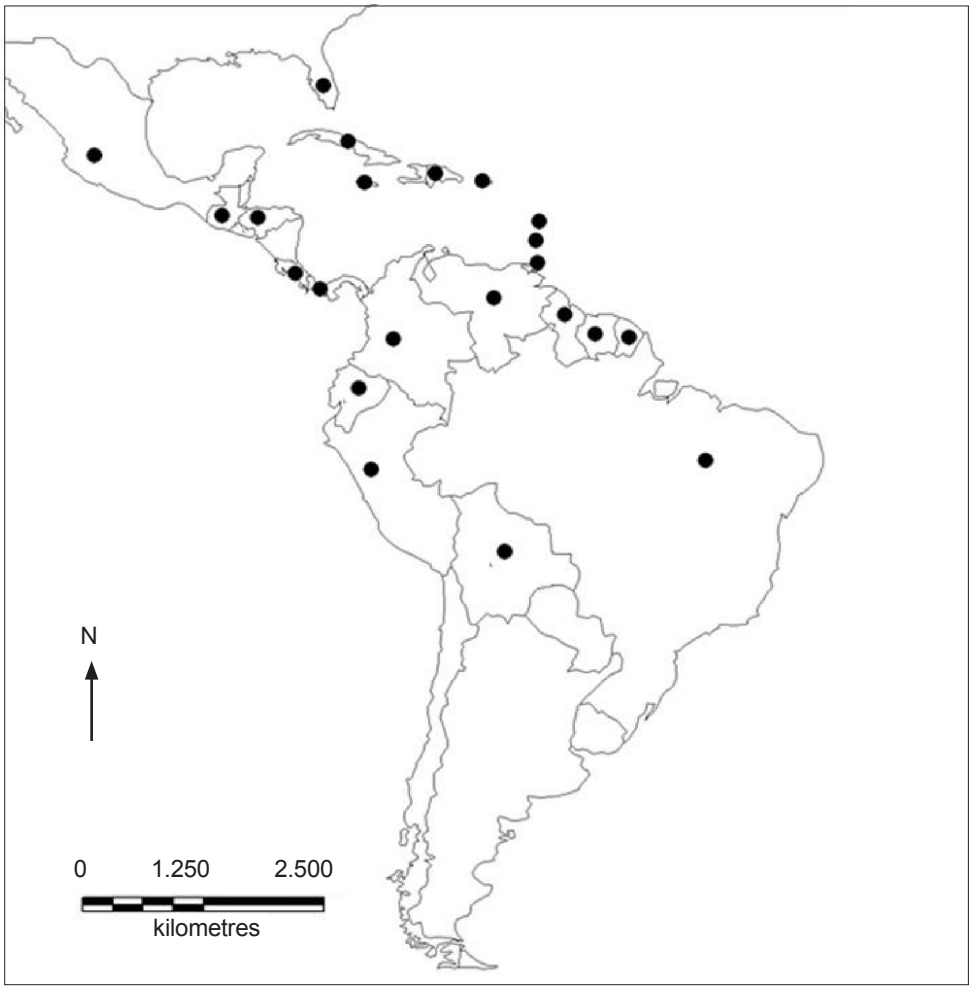

Figure 1 *Piper aduncum* in Central and South America and the Caribbean. It has been reported in Belize, Bolivia, Colombia, Ecuador, El Salvador, Honduras, Panama, Mexico, Costa Rica, Guatemala, Panama, Brazil, Peru, Venezuela, Surinam, French Guyana, Cuba, Trinidad and Tobago, Jamaica, Martinique, St Vincent, Dominican Republic, Southern Florida and Puerto Rico (USA).

for medicinal purposes via the internet (www.tropilab.com/spikedpepper.html).

Piper aduncum in South-East Asia

Piper aduncum was introduced to the Botanical Gardens of Bogor, Indonesia in the 1860s, possibly as an ornamental. It is not known where the plants or seeds came from or by whom it was introduced. By the 1920s, however, *P. aduncum* commonly occurred in a radius of 50 to 100 km around the Botanical Gardens in young secondary vegetation, close to rivers and on very steep slopes, locally in dense stands up to 1000 m (Heyne 1927).

Some information of its spread in Indonesia can be obtained from specimens at the National Herbarium in Leiden (Netherlands). As of January 2005, the herbarium has 112 specimens collected from 16 countries (Table 1). A total of 51 specimens were from Indonesia, 23 from elsewhere in Asia and the Pacific, 31 from South and Central America and 7 from unknown locations. The earliest specimens were collected from Puerto Rico in 1827 and from Surinam in 1827, whereas the most recent additions were dated in the 1980s. The first Leiden specimen from Indonesia was collected in 1888 at the Botanical Gardens in Bogor. In total, 23 specimens have been collected from other parts of West Java, but the herbarium has no specimens from Central or East Java.

In the late 1930s, it was collected in South Sumatra, in the 1950s in West Sumatra, and in

Table 1 Overview of *Piper aduncum* specimens at the National Herbarium Leiden (Netherlands) grouped by country, province and first year of collection

Country	Province/region	Number of specimens	Year	Location
Indonesia	Java	23	1888	Bogor (West Java)
			1925	Jakarta (West Java)
			1932	Pelabuan Ratu (South-West Java)
			1937	West Banten (West Java)
			1948	Bandung (West Java)
			1959	Gunung Salak (West Java)
			1963	Ujong Kulong National Parc (West Java)
	Sumatra	12	1939	Lampung (South Sumatra)
			1953	Padang (West Sumatra)
			1973	Bukit Lawang (North Sumatra)
			1979	Gunung Leuser (North Sumatra)
			1982	Bukit Tingi (West Sumatra)
	Kalimantan	8	1952	West Samarinda
			1981	Balikpapan
	Sulawesi	1	1985	Dumola Bone
	Moluccas	1	1974	?
	West Papua	6	1955	Waigeo island
			1957	Jayapura
			1960	Biak
Malaysia	Selangor	6 (total)	1960	
	Kuala Lumpur		1968	Gombak
Papua New Guinea	Morobe	10 (total)	1935	Heldsbach
			1952	Lae, Botanic Gardens
			1964	Pindiu, Mongi valley
			1977	Wau-Bulolo road
	Central		1970	Koiari
			1980	Near Sogeri Local government
	Manus		1971	Los Negros Island
Fiji	Viti Levu	3 (total)	1953	
	Vatuwaqa		1955	
Solomon Islands	Ghairanu	3	1969	Nuta river area
Philippines	Manila	1	1929	(by M Clemens)
USA—Puerto Rico		3	1827	
Surinam		6	1827	
Tobago		3	1889	
Colombia		1	1900	
West Indies		1	1904	
Guatemala		3	1906	
Mexico		7	1865/1909	
Peru		1	1947	
Belize		1	1973	
Brazil		5	undated	

the 1970s in North Sumatra. It is probable that the plant had crossed the Sunda Strait in the 1930s and spread to the west and east in the following decades. In West Papua (Irian Jaya), it was collected from Jayapura and Biak in 1957 and 1960 respectively. In Kalimantan, it was first collected in 1952 near Samarinda, whereas in the Moluccas and Sulawesi it was collected in 1974 and 1985 respectively. Recent surveys have confirmed *P. aduncum* near Jayapura, Nabire and Sorong in West Papua (Waterhouse 2003), Kalimantan (Hashimotio *et al.* 2000) and Sulawesi (Lee & Riley 2001).

In Malaysia, it was present in the 1960s (Allen 1966, Chew 1972) and there are large areas of *P. aduncum* in Genting Highlands and along the road to Kuala Lumpur (EA Hartemink, personal observation). It has been recorded in Singapore in 2003 (J. Vermeulen, personal communication). The botanist Mary Clemens collected *P. aduncum* near Manila in the Philippines in 1929, of which a specimen is in the Leiden Herbarium. She was also the first person to describe *P. aduncum* in Papua New Guinea (Hartemink 2001). Figure 2 shows the places where *P. aduncum* have been reported in South-East Asia and the Pacific.

Piper aduncum in the Pacific

There are several economically important *Piper* species in the Pacific, including *Piper nigrum* (pepper), *Piper methysticum* (kava) and *Piper betle*, of which the fruits are used with betel nut (*Areca catechu*) in Papua New Guinea (Bornstein 1991). In 1988, Swarbrick (1997) surveyed weeds of countries and territories in the Pacific Islands, including American Samoa, Cook Islands, Fiji, Kiribati, Nauru, New Caledonia, Solomon Islands, Tonga, Tuvalu, Vanuatu, Western Samoa, Yap, Chuuk, Pohnpei in the Federate States of Micronesia, and Guam and Palau (Figure 2). His report listed 517 species of weeds that had been

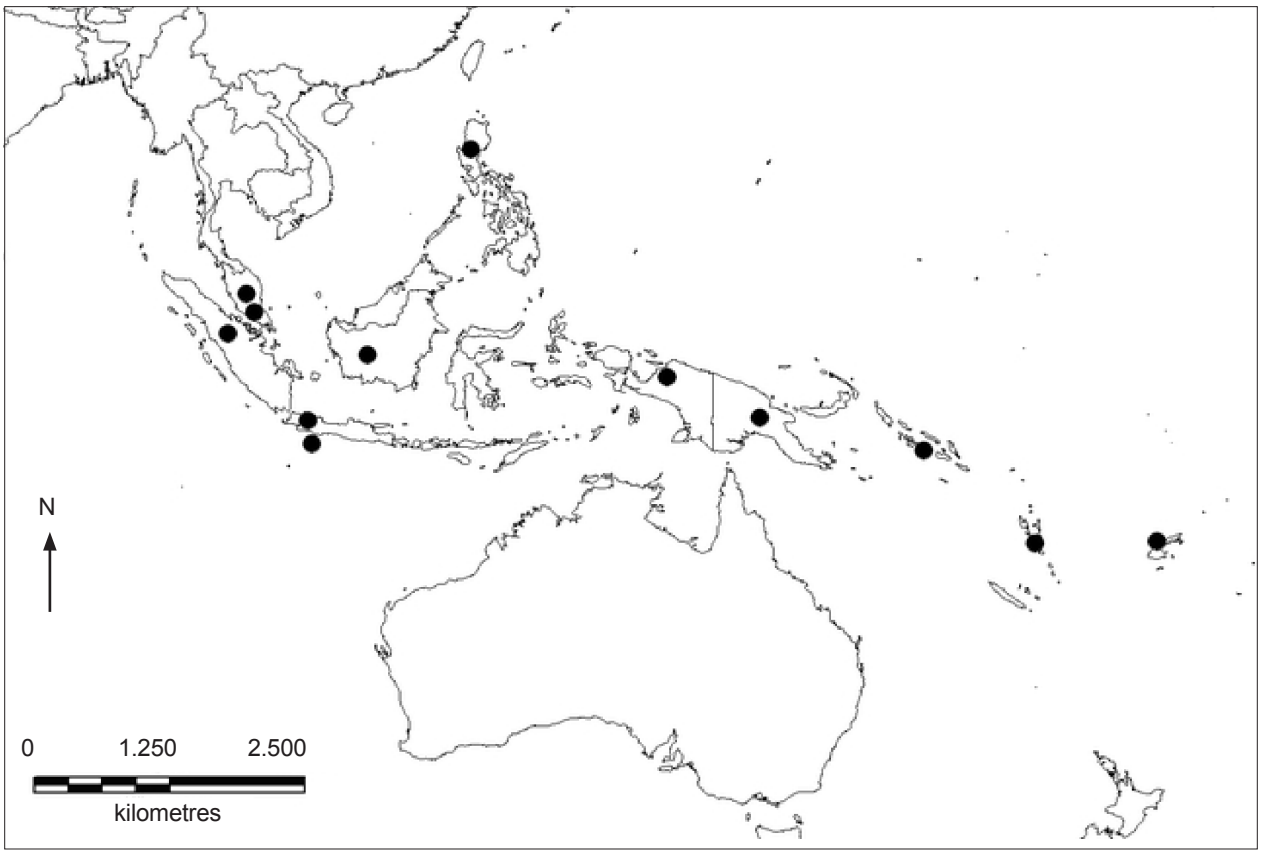

Figure 2 *Piper aduncum* in South-East Asia and the Pacific. It has been reported in Malaysia, Indonesia, Philippines, Papua New Guinea, Solomon Islands, Vanuatu, Fiji and also in Hawaii (USA), Micronesia, American Samoa, Niue, the Marianas, Tonga, Samoa, the Cook Islands and Palau (not all in the map).

recorded in the Pacific Islands and provided details on the 18 most important weeds and methods of control. *Piper aduncum* was not among these 18 but was only listed as occurring in Fiji and the Solomon Islands. In both countries, it occurred in pastures and on wastelands and along roadsides (Swarbrick 1997).

Piper aduncum is widespread in the wet and intermediate zones of Viti Levu in Fiji (Parham 1972), where it is named 'false kava'. It was first recorded in 1926 (Smith 1981) and is thought to have arrived with packing materials at the port of Suva, as it seems to have spread out there along roadsides (Englberger 2001). Contrary to the findings of Swarbrick (1997), *P. aduncum* is present in Vanuatu where it is also named 'false kava' (Englberger 2001). *Piper aduncum* has been recorded as a naturalised species on Christmas Island and also occurs in Hawaii (Maui) where it is on the noxious weed list. There was no *P. aduncum* in Hawaii in the late 1970s, according to Smith (1981).

Piper aduncum is present near Kombe and the Nuta River area in the Solomon Islands where it was identified (or collected) in 1969 (A Bornstein, personal communication), thus confirming the survey by Swarbrick. Swarbrick's (1997) survey had been updated by Space (2002). He had resurveyed Micronesia, American Samoa, Niue, the Marianas, Tonga, Samoa, the Cook Islands and Palau, under the aegis of the Pacific Island ecosystems at Risk (PIER) project (Space 2002). Although there was some confusion about the identification of *P. aduncum*, the surveys showed that it was widespread throughout all the countries surveyed.

Piper aduncum is not present in the humid coastal regions of northern Australia but is in the list of unwanted weed species by the quarantine service (Waterhouse & Mitchell 1998). Like many weeds, it may have already been present and is only awaiting discovery (Waterhouse 2003).

Piper aduncum in Papua New Guinea

It is not known precisely when or how *P. aduncum* arrived in Papua New Guinea. Two theories could be explored based on accidental or deliberate introduction from the east (Pacific) or from the west (Indonesia, South-East Asia). *Piper aduncum* could have island hopped from its origin in Central America across the Pacific via Hawaii or Fiji, where it was found in the 1920s and was brought in through Suva (Englberger 2001). Seeds could have been transported by travellers or perhaps in the tyres of military trucks and machinery. Kidd (1997) surveyed *P. aduncum* in the Wau Area of Morobe Province and suggested that it might have been introduced during the Second World War, possibly via Finschhafen. However, that is not the case as Mary Clemens first observed *P. aduncum* in 1935 near the Heldsbach mission station near Finschhafen (Table 1). Even though it was already present before the Second World War, further imports to Papua New Guinea may have occurred during the war, either accidentally or deliberately. The Americans built many roads around the capital of Port Moresby and presumably *P. aduncum* was planted as a slope stabiliser to prevent soil erosion.

Alternatively, and more likely, it may have arrived in Papua New Guinea from Indonesia via West Papua. It had been introduced in the 1860s in West Java (Bogor) and was intentionally, or by accident, taken to West Papua (with the first botanical records dating to the 1950s—see Table 1). The plant could have moved along the north coast of New Guinea from Jayapura to Vanimo and Wewak, and then further east to Heldsbach—the Lutheran mission station where it was described by Mary Clemens in 1935. It may have been transported or imported by missionaries for use as erosion control on steep slopes. In the Dutch East Indies, contour planting was actively promoted by the government in the late 1800s.

Below is a summary of the literature on *P. aduncum* in Papua New Guinea concerning the spread and significance in different parts of the country. Three periods are distinguished: from the first collection in 1935 till the early 1970s; the 1970s till the 1980s when it spread rapidly in the lowlands and reached the highlands; and the 1990s till the present when it began to receive research attention (Hartemink 2006).

First records 1930–early 1970s

The first record of *P. aduncum* in Papua New Guinea was the collection in 1935 of a specimen in the Finschhafen area (Table 1). The first collection record held in the Lae Botanical Garden of Papua New Guinea was dated 1952 (Henty & Pritchard 1988). This was followed 10 years later by a collection from the same location (Hartley *et al.* 1973). These three collections (1935, 1952, 1964), two of which came from plants in the Botanical

Garden, and all of which were from a small area of Morobe Province, suggest a restricted distribution up till the 1960s. This is supported by the absence of mention of the plant in the overview of Papua New Guinea weeds (Henty 1972), and overall *P. aduncum* was not common in published lists or accounts of vegetation during the 1960s and 1970s (e.g. Paijmans 1976).

At the CSIRO Herbarium (Canberra, Australia), there are only two further collections from Papua New Guinea between 1964 and 1970, and both were from Morobe Province. One was collected at Pindiu on the Huon Peninsula at about 800 m asl in a swampy area with sago, the other from secondary growth at or near Lae. Two further records from 1970 till 1971 showed that the plant was more widely dispersed. In 1970, it was collected from the Koiari area of Central Province and in 1971, from Los Negros Island in Manus Province.

Rapid spread in lowlands, introduction to highlands mid-1970s–1980s

In the mid-1970s, *P. aduncum* reached the central highlands, probably by the direct agency of people (Sterly 1997). It is unlikely that it had reached the highlands before 1975 as there are a number of localised surveys before then that did not report *P. aduncum* (Powell 1974, Hide *et al.* 1979, Hays 1980).

In 1980, in the south of Chimbu Province, it was observed as a planted ornamental or fence plant at the aid post in the settlement of Yuro (1150 m), near Karimui station by Hide (1984). In the north of Chimbu Province in early 1984, Sterly (1997) collected two specimens of *Piper* that are likely to be *P. aduncum*. They were said to have been introduced in the late 1970s from the coast. Both trees had been planted and one had been transplanted from Iower in the Wahgi valley. In the early 1980s, three collections of *P. aduncum* were made in coastal villages in the Finschhafen area at Keregia and Nasingalatu (Holdsworth & Damas 1986) and at Suquang (Woodley 1991). Between 1974 and 1985 on Kairiru Island (East Sepik province), Borrell (1989) noted the presence of *P. aduncum*. From 1987 till 1988, *P. aduncum* was collected in the Teptep area of the Finisterre Range on the Morobe–Madang border (Kocher Schmid 1991) and in late 1988, at Gawam village, 20 km north-east of Lae at 200 to 300 m asl (Baltisberger *et al.* 1989).

Age of discovery—1990s

In the 1990s, awareness of the spread of *P. aduncum* grew and there was a corresponding increase in research interest in the plant from a range of disciplines (e.g. pharmacology, agronomy, quarantine aspects, forestry, taxonomy).

From 1992 till 1995, its significance as an invasive plant in several areas of Morobe, Northern and Central Provinces was documented by teams of the joint survey of agricultural systems by the Australian National University (Canberra) and the Department of Agriculture and Livestock in Papua New Guinea (Bourke *et al.* 1998). An important part of these agricultural system surveys was the description of fallow types and species. In the Kaiapit area of the Morobe Province, over 75% of land in cultivation is planted in a sweet potato–peanut rotation. Short woody regrowth dominated by *P. aduncum* and 6 to 10-year-old fallows are cleared and burnt. *Piper aduncum* was accidentally introduced but generally thought to be beneficial. The fallow vegetation has changed from mainly cane grass to short woody regrowth, following the introduction of *P. aduncum*. The Wantoat Valley was described as a 'densely-populated grass flat' in 1936 and in the late 1950s cane grass was the dominant fallow vegetation—now it is *P. aduncum* (Bourke *et al.* 2002).

The main valley floors and lower slopes in the Hiri District of the Central Province were planted with rubber in the early 1900s. The surrounding hill country was logged over in the 1970s. The hillsides are now covered with short grass, pure stands of *P. aduncum* or a much reduced hill forest. A landuse system was introduced to the area by settlers from the Morobe Province. *Piper aduncum* sticks were used to prevent soil erosion and the invasion of cultivated areas by grasses. During forest clearing, *P. aduncum* sticks were cut and hammered into the ground with wooden mallets. Other sticks were tied onto these stakes horizontally with vines. Soil was then cut from immediately beneath the fence above and shovelled against the back of the fence to form a terrace. Long fallows were less than five years. During this time, *P. aduncum* stakes begin to grow and the fallow site quickly becomes covered in a pure stand of *P. aduncum*, about 3 to 5 m tall. The plant is said to maintain a friable soil and to prevent the establishment of *I. cylindrica* grass. It also provides the material from which soil retention barriers are constructed at the next

cultivation. Terraces cover extensive hillsides in the region and large areas of piper fallows also exist (Allen *et al.* 2002).

In parts of the Northern Province of Papua New Guinea, short woody re-growth, dominated by *P. aduncum*, is the dominant fallow vegetation. *Piper aduncum* is a recent introduction and is known locally as 'poroporo'. It is considered to be a useful introduction and is spread mainly by a small bat.

Hartemink and co-workers started a series of experiments in the mid-1990s focusing on soil seed banks (Rogers & Hartemink 2000), nutrient and biomass accumulation (Hartemink 2001, Hartemink 2004), biochemical properties and decomposition of the leaves of *P. aduncum* (Hartemink & O'Sullivan 2001), and the effects of *P. aduncum* fallows on soils and subsequent agricultural crops (Hartemink 2003a, Hartemink 2003b). It was found that the aboveground biomass of *P. aduncum* increased linearly and reached 48 Mg dry matter (DM) ha^{-1} within two years. Growth rates averaged 69 kg DM ha^{-1} day^{-1} and increased with higher rainfall. *Piper aduncum* accumulated large amounts of potassium, which is particularly important for sweet potato that dominates the cropping phase in the shifting cultivation systems. The rates of biomass and nutrient accumulation are in the highest range found for secondary fallow in the tropics and may explain the dominance of *P. aduncum* over natural vegetation.

The effects of *P. aduncum* invasion on rural livelihoods were investigated in three villages in Morobe Province (Siges *et al.* 2005). In these villages, *P. aduncum* was first introduced in the 1930s but now dominates the secondary fallow vegetation. The tree and its products (stems, leaves, mulch, ashes) are used in farm practices, in the household and for medicinal applications. The invasion and dominance of *P. aduncum* have led to the destruction of natural forest and the loss of natural secondary fallow vegetation. Villagers found several new uses for *P. aduncum* and its products, so it became both a resource to which they were forced but which they also chose to use. The research showed that eradication and control programmes for invasive plants should take into account the adaptation of the plants and its effects on rural livelihood.

Following pharmacological collections in 1988 (Baltisberger *et al.* 1989), the chemical properties of the plant were described in a series of papers which reported on some of the antibacterial and molluscicidal compounds (Orjala *et al.* 1994). In the early 1990s, scientists from the Christensen Research Institute at Madang undertook work on the plant's response to disturbance (Lovelock *et al.* 1994).

Between 1996 and 1999, botanical inventory surveys in several conservation areas recorded the presence of *P. aduncum* in Morobe, Madang and Simbu province (Takeuchi 1999, Takeuchi 2000). It was not reported in other provinces, such as at Lakekamu in Gulf Province, in the Bismarck–Ramu region in Western Highlands and Madang Province, and in Southern New Ireland (Takeuchi & Wiakabu 2001). Gardner (2003) published a taxonomic account of six *Piper* species by examining specimens from various herbaria and conducting some field work in the Madang Province of Papua New Guinea. He noted that *P. aduncum* was abundant at least in drier parts of the Morobe Province, mostly in disturbed secondary vegetation and fallow gardens. He described the altitudinal limit at about 1500 m asl (Gardner 2003), which is much lower than the Chimbu data of Sterly (1997) and others.

From the late 1990s, entomological work was carried out in the Madang area by scientists attached to the Parataxonomist Centre (Leps *et al.* 2002, Novotny *et al.* 2003). At the same time, Australian interest in the quarantine aspects of the invasive nature of *P. aduncum* increased (Waterhouse 2003).

Figure 3 shows the presence of *P. aduncum* in Papua New Guinea based on observations and publications by workers in ecology, geography and agriculture.

DISCUSSION AND CONCLUSIONS

The invasion

Although the exact details concerning the introduction of *P. aduncum* to Papua New Guinea are not known, it spread through many parts of the lowlands through fruit dispersion by birds, bats and the wind, as well as by logging equipment, and in some localities by migrating people. The introduction into the highlands was possibly by people as they planted *P. aduncum* as a hedge or ornamental tree.

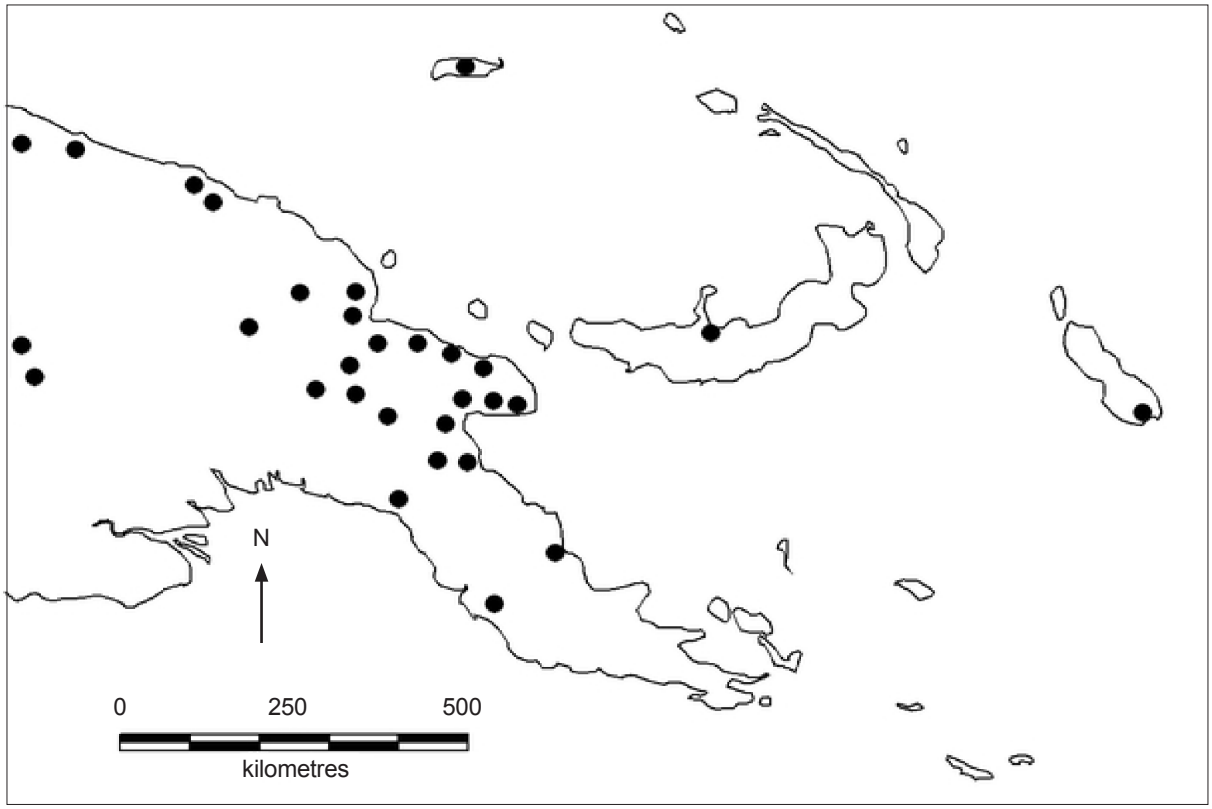

Figure 3 Presence of *Piper aduncum* in Papua New Guinea based on observations and publications by BJ Allen, RMBourke, M Clemens, RO Gardner, AE Hartemink, R Hide, SB Kidd, C Kocher-Schmid, J Leps, AL Mack, O Ngere, V Novotny, J Sterly, W Takeuchi, P Vovola, B Waterhouse and M Woruba

In Papua New Guinea's lowland forests, which are subject to catastrophic natural disturbances, such as landslides or stand-devastating windthrow, *P. aduncum* may pose a serious threat to the indigenous flora by outcompeting other pioneer species. Moreover, anthropogenic factors contribute to the spread of *P. aduncum* through logging and shifting cultivation. Forest fires, which were particularly severe in the 1997/98 El Niño Southern Oscillation may present new frontiers for *P. aduncum* invasion (Rogers & Hartemink 2000).

None of the sources of *P. aduncum* in South America mentioned about the formation of monospecific stands or aggressive invasion. Only in Malaysia and in Kalimantan do such stands occur. In the Papua New Guinea lowlands, monospecific stands—'wheatfields' according to Waterhouse (2003)—are common as *P. aduncum* is able to outcompete and smother seedlings of other species. In the highlands above 1000 m, such monospecific stands are not seen and *P. aduncum* occurs only as single trees along roads, in gardens or in disturbed areas. Apparently in the highlands, it is unable to form such stands and cannot outcompete indigenous fallow trees and shrubs.

At sites near Lae, *P. aduncum* has been reported to outcompete another plant invader, *C. odorata* (Orapa 2001). It also invades grasslands. Bourke *et al.* (2002) surveyed part of the Huon peninsula and found that the fallow vegetation changed from mainly cane grass to short woody re-growth, following the introduction of *P. aduncum*, which is now the dominant species. In 2000, near Nadzab Airport in the Markham Valley of Morobe, individual *P. aduncum* trees had begun to invade the *I. cylindrica* grasslands. Although it is too early to tell if such trees will survive the regular fires that sweep through such grasslands, this appears to be another case where *P. aduncum* can outcompete other vegetation types.

The monospecific stands in the lowlands are temporary as the growth of *P. aduncum* eventually levels off. In Morobe Province, it was observed that other species slowly invade the monospecific *P. aduncum* stands after about 5 to 10 years.

Future research

As shown in the previous section there has been some research on *P. aduncum* in forestry (Saulei 1989), pharmacology (Orjala *et al.* 1994), mapping agricultural systems (Bourke *et al.* 1998), entomology and ecology (Leps *et al.* 2002, Novotny 2003), agriculture (Hartemink 2006), and socio-economics (Siges *et al.* 2005), but the amount of research on its invasion is fairly limited, particularly given its widespread distribution. Most of the research has been conducted on a single location, lacks multi-ecoregional focus and is short-term. Therefore, four areas of research require attention.

Firstly, there is a need to map its current distribution in Papua New Guinea and the patterns and rates of spread across the country. *Piper aduncum* occurs in most provinces of Papua New Guinea, but current information is only qualitative; no information on areal extent and impact is available. With current satellite imagery, mapping different vegetation types is feasible and use of images from different periods should make it possible to map changes over time. Moreover, it may be possible to detect *P. aduncum* areas in other locations where it has not been previously reported. This is an important quantitative step that would assist future planning policies on eradication or setting ecological or agronomic research priorities.

Secondly, there is a need to assess the impact of *P. aduncum* invasion on local biodiversity —an issue that is poorly studied. The loss or transformation of natural (secondary) vegetation as a consequence of the expansion of *P. aduncum* has received little research attention, including the loss of species or the changing composition of fallow vegetation.

Thirdly, researches on growth rates, biomass and nutrient accumulation or the modes of invasion have been conducted only in the humid lowlands of Morobe and Madang province. No ecological or agronomic research has been conducted in other parts of the country where *P. aduncum* is increasingly important, such as parts of East Sepik, Central and Northern provinces. In these provinces, it may have already significantly altered ecosystems and farming systems.

Finally, research has shown that farmers adapt rapidly to the invasion of *P. aduncum* and that replacement of natural secondary vegetation or grasslands to *P. aduncum*-dominated fallows is not necessarily negative (Siges *et al.* 2005). Additional socio-economic surveys on how *P. aduncum* is used by farmers are needed. These aspects are neglected in most of the literature on plant invaders at the expense of other issues such as loss of biodiversity and eradication programmes.

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